Europe's concept and plans for a Venus Entry Probe Mission

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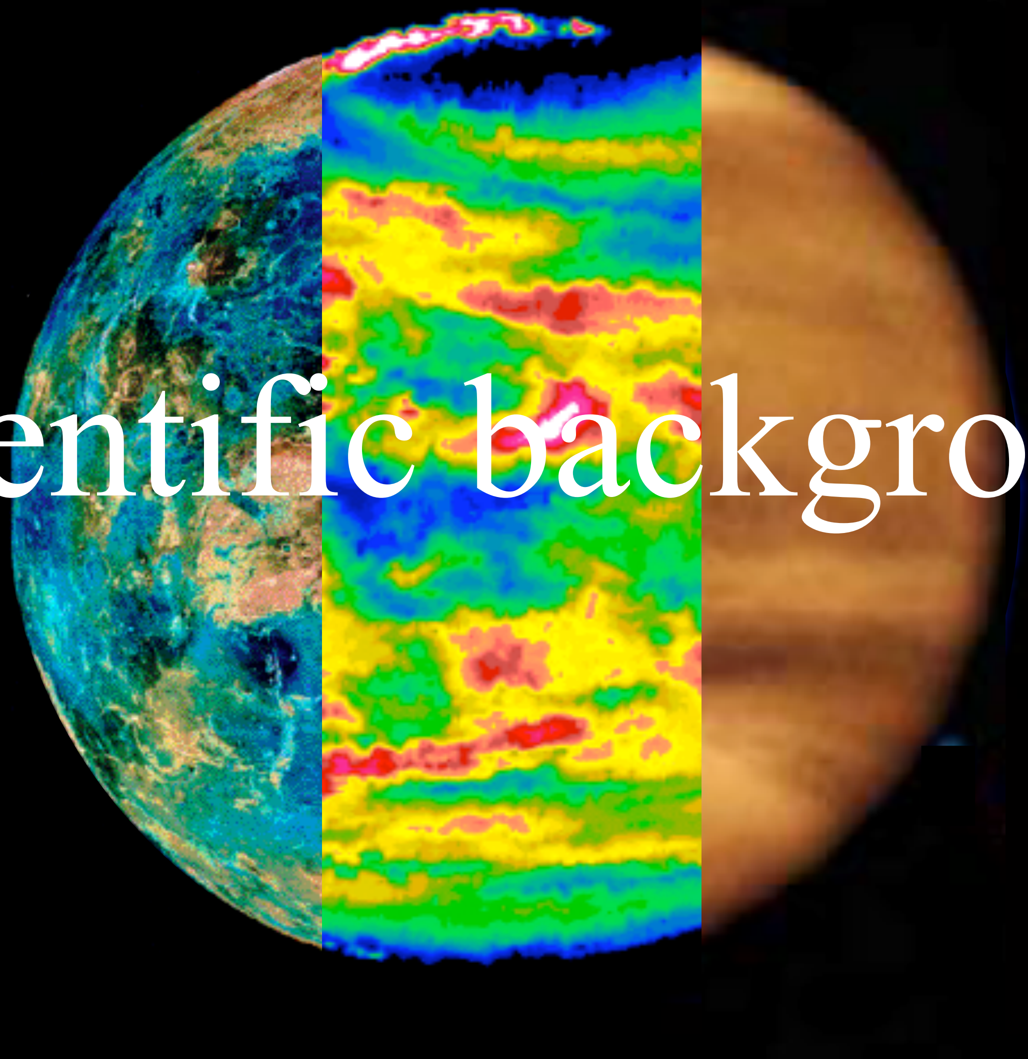
Scientific background

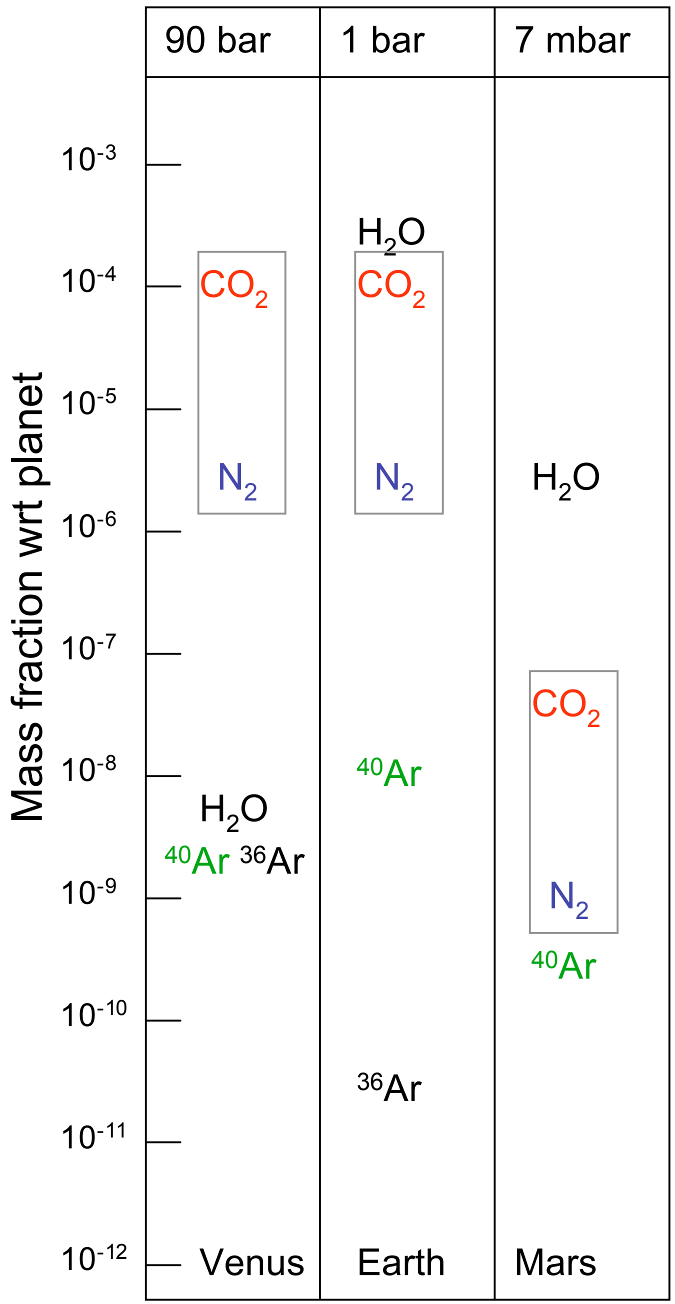


Compared characteristics of terrestrial planets atmospheres

	Venus	Earth	Mars
Surface temperature	735 K	288 K	218 K
Black body temperature	230 K	255 K	215 K
Greenhouse gases	CO_2, H_2O, SO_2, CO, clouds (H_2SO_4…)	H_2O, CO_2, O_3, …	CO_2
Grenhouse effect	505 K	33 K	3 K

- Mars : tenuous atmosphere, ≈ no greenhouse.
- Earth : moderate greenhouse, liquid water, O_2 photosynthetic, CO_2 in carbonates.
- Venus : massive atmosphere, strong greenhouse.

Volatile inventory of terrestrial planets



- CO_2 and N_2 : Venus resembles Earth, but Mars is depleted by 3 orders of magnitude
- H_2O : Venus is much dryer than Earth and Mars.
- ^{40}Ar mixing ratio : Mars is enriched by ≈100, Venus depleted by ≈4 (wrt Earth) .
- ^{36}Ar mixing ratio: Venus is enriched wrt Earth (≈70) and Mars (700)

Why is Venus different from Earth?

- Why is there virtually no water on Venus (a few 10 precipitable cm)?
  - ➔ Runaway (or moist) greenhouse (Rasool and DeBergh, 1970) occurred in primitive intense EUV/ solar wind conditions **(?)**
- Why is there 4 times less argon 40 than in Earth atmosphere?
  - ➔ Outgassing ceased ≈300 Myr after Venus formation, before most of Ar is formed within the interior (by K radioactive decay) **(?)**
- Why is there 70 times more argon 36 than on Earth?
  - ➔ Preplanetary grains which have formed Venus have been enriched in volatiles through solar wind implantation **(?)**

What was the fate of oxygen on Venus?

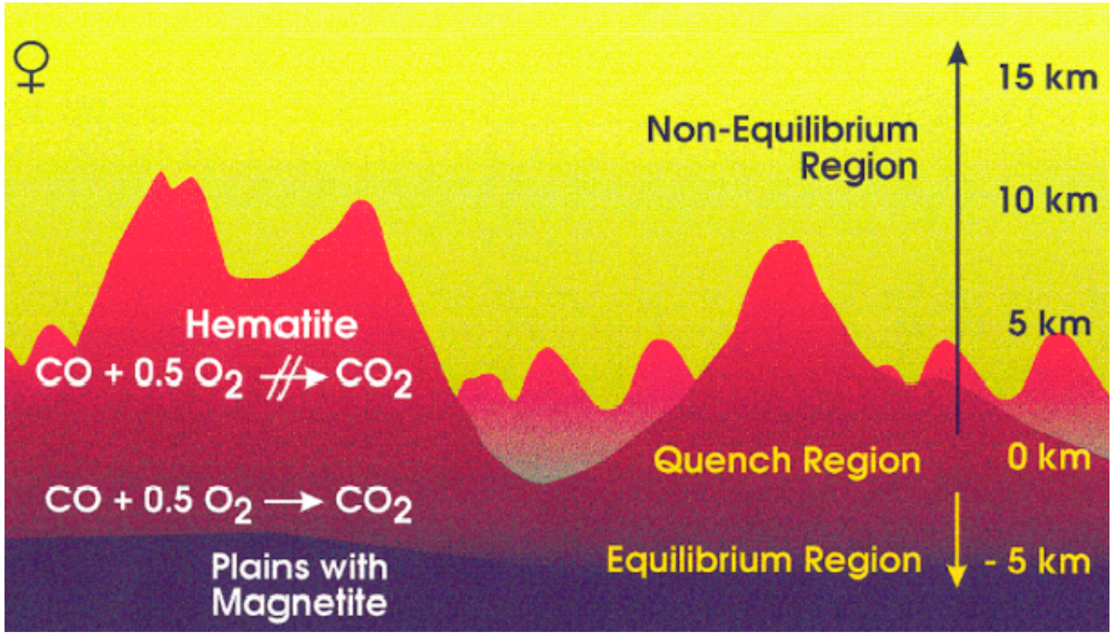
- Virtually no oxygen in Venus atmosphere. Why?
  - Oxygen was removed by oxidation of rocks. Assuming $FeO \rightarrow Fe_2O_3$, required crust production rate of ≈15 km^3/yr (≈ Earth rate). *Not consistent with low ^{40}Ar (weak outgassing > 300 Myr)*.
  - Oxygen was lost by impact erosion. *Not consistent with CO_2/N_2 inventory similar to Earth*.

  ➔ <u>Oxygen was lost by hydrodynamic escape : dynamically and energetically possible</u> (Chassefière, 1996).

  ➔ <u>Possible role of sputtering</u> (Kulikov et al, 2006).

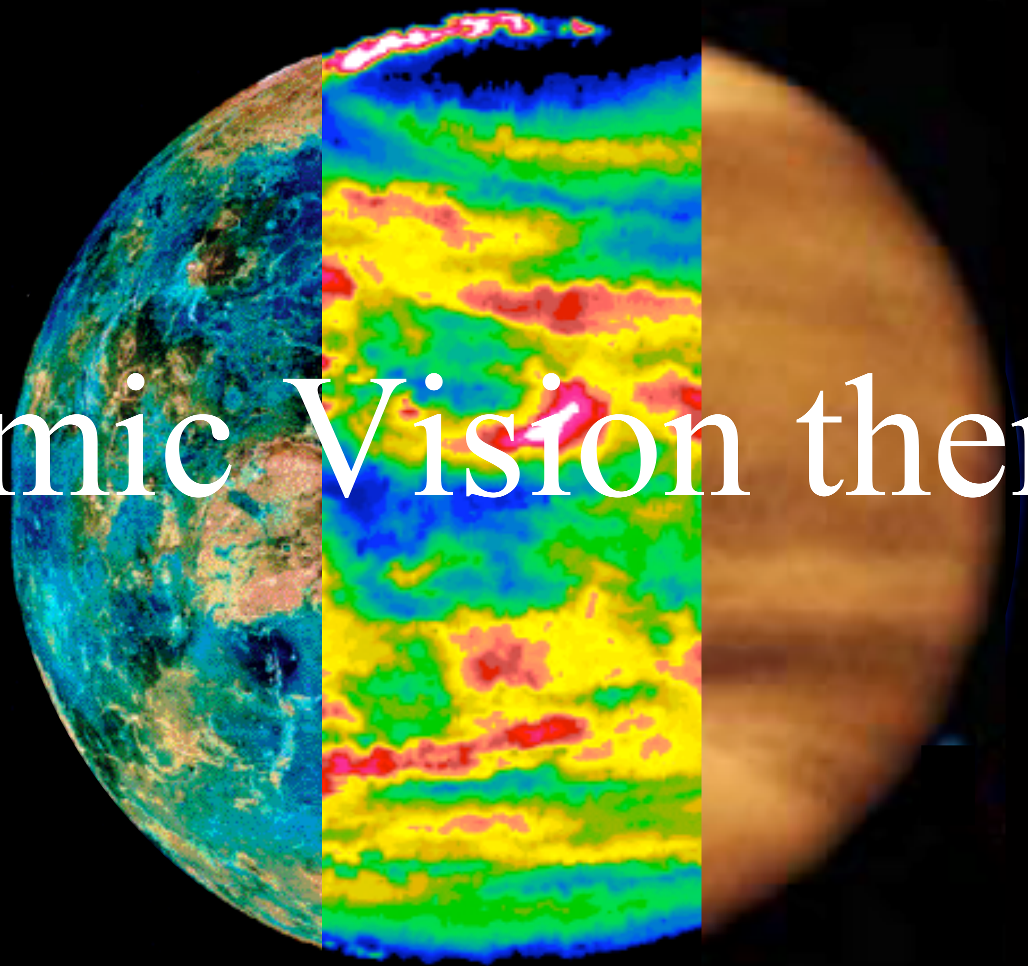
How does the Venus climate system work?

- What is the redox state of the low atmosphere, and its variations with surface elevation?
- Is the atmosphere at thermochemical equilibrium with the surface?
- What are stable mineral phases at the surface?
- Is the Venus climate stable at geological time scales?



From Fegley et al, 1997

Cosmic Vision themes



Addressed Cosmic Vision themes (1)

What Are The Conditions For Planet Formation And The Emergence Of Life? From Extra-Solar Planets To Biomarkers.

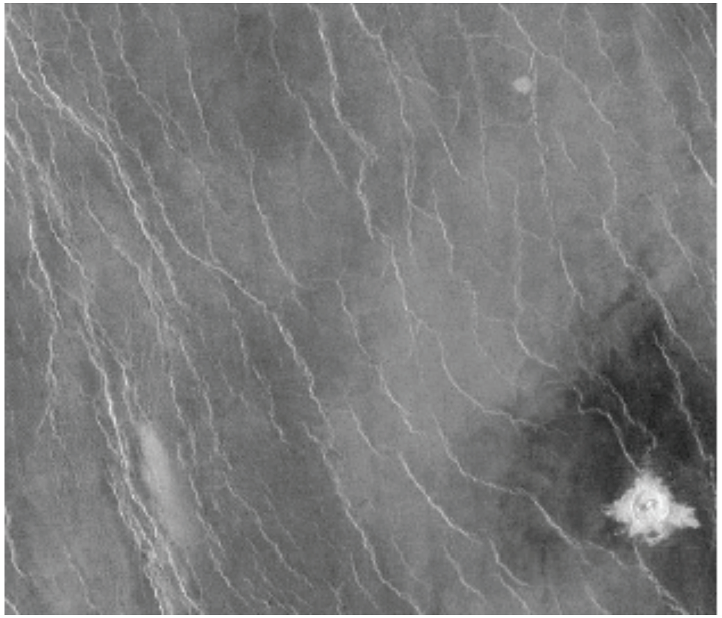
Constructing evolution scenarios of Earth-like extrasolar planets

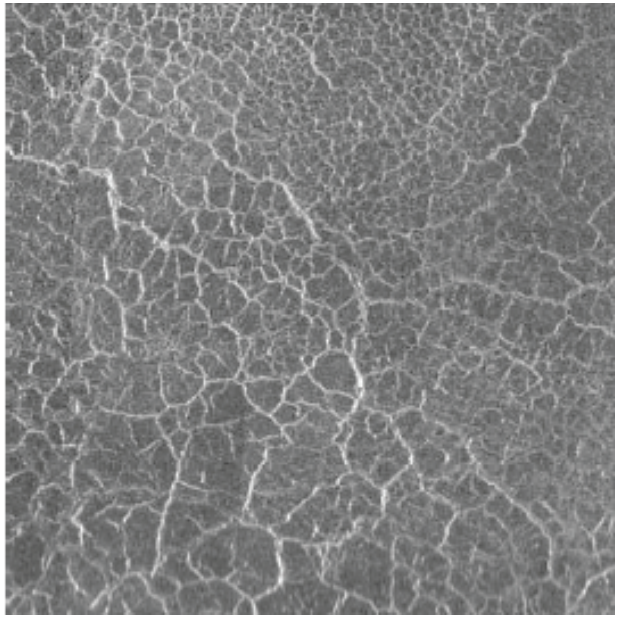
How can the detailed knowledge of the atmosphere of Venus, compared to that of the two other terrestrial planets, help in understanding future observations of Earth-like extra-solar planet atmospheres and the search for habitability, and possibly life, signatures?

Main questions in this theme

- Is the present bulk atmosphere of Venus in thermo-dynamical equilibrium with the surface and, if not, what are the processes responsible for a thermo-dynamical disequilibrium?
- Earth-size extra-solar planets can develop a massive a-biotic oxygen atmosphere by means of a runaway greenhouse and escape of hydrogen to space?
- What does the atmospheric dynamics and climate of a slowly rotating Earth-type extra-solar planet, phase-locked to its central star, look like?

Addressed Cosmic Vision themes (2)





What Are The Conditions For Planet Formation And The Emergence Of Life? Life And Habitability In The Solar System.

Assessing the capability of the ancient Venus to have been habitable

Did Venus, which is the most Earth-like planet of the Solar System, offer suitable atmospheric and geological conditions for life to emerge at some time in the past? Why did it evolve differently from Earth, and will Earth evolve toward a Venus-like state in the future?

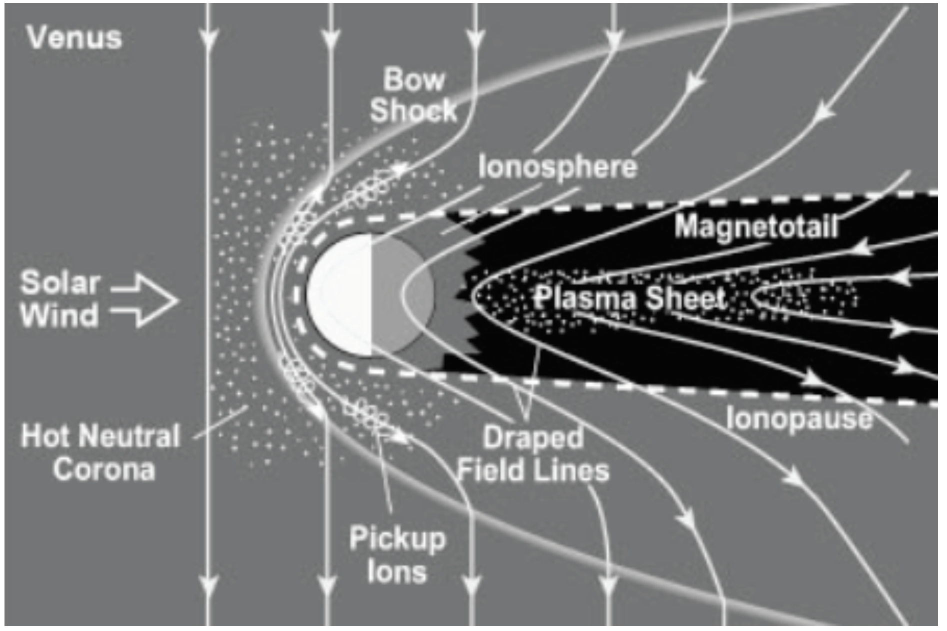
Main questions in this theme (1)

- Was Venus originally endowed with as much water as Earth and, if so, where did water go?
- Did the massive greenhouse atmosphere have an impact on the geological history of the planet, and therefore its potential to host life, e.g. by modifying the way volatile species are cycled through the mantle, or by changing upper boundary thermal conditions?
- What is the impact of cloud coverage on atmospheric greenhouse and climate, and did clouds play a significant role in the climatic evolution of terrestrial planets?

Main questions in this theme (2)

- Was Venus suitable to the appearance of life at some time in the past and, if so, when and how did conditions become unfavourable for life?
- How are volatile species cycled through the complex mantle-crust-surface- atmosphere-cloud system, and to which extent do global scale chemical cycles control bulk atmosphere composition?
- Will Earth evolve toward a massive Venus-type greenhouse by future increasing solar radiation conditions and anthropogenic influence?
- How does a dry, one-plate, planet of Earth size drive and lose heat from inner layers to its outer environment?

Addressed Cosmic Vision themes (3)



How Does The Solar System Work? From The Sun To The Edge Of The Solar System.

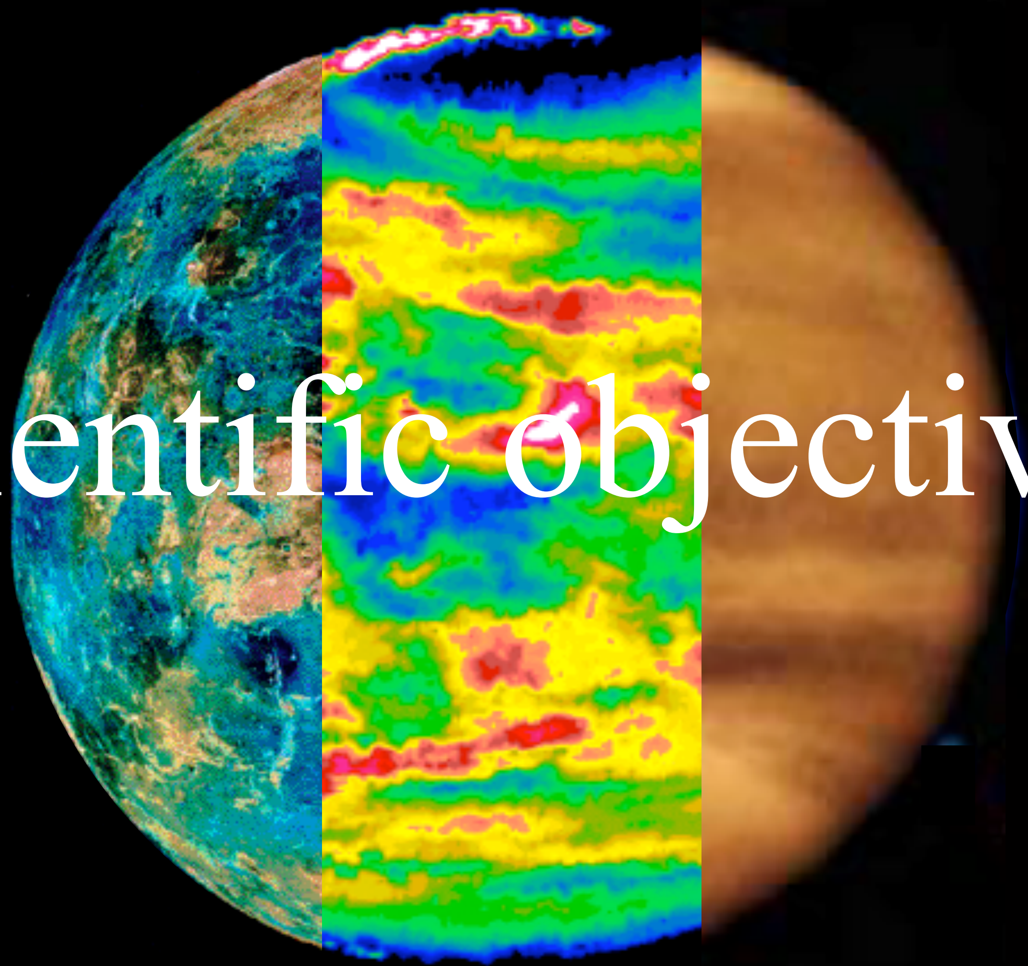
Understanding how did Venus evolve in response to solar evolution

How does the Sun interact with Venus' atmosphere, through its radiation and particle emissions and what has been the influence of the Sun and of its evolution on the climate history of Venus?

Main questions in this theme

- How does an Earth-sized planet without global magnetic field interact with the solar wind and why and at which rate does it lose its atmosphere?
- Does Venus' atmosphere, ionosphere and solar wind interaction region present an electromagnetic wave activity, due to various possible phenomena: seismic and/or volcanic activity, atmospheric lightning, solar wind interaction?
- Did solar evolution (radiation/ particle) play an important role in driving terrestrial planetary climate evolution, e.g. powering runaway greenhouse on Venus or massive escape on Mars, and determining the presence or absence of water at their surface?

Scientific objectives



Unanswered questions (1)

1) The *isotopic composition*, especially that of noble gases, which provides information on the origin and evolution of Venus and its atmosphere.
2) The *chemical composition below the clouds and all the way down to the surface* with more detail than is possible using remote sensing, in order to fully characterize the chemical cycles involving clouds, surface and atmospheric gases.
3) The *surface composition and mineralogy* at several locations representing the main types of Venus landforms and elevations.
4) A *search for seismic activity and seismology on the surface*, and measurements at multiple locations to sound the interiors.

Unanswered questions (2)

5) *In situ* investigation of the *atmospheric dynamics*, for instance by tracking the drift of floating balloons.
6) The *composition and microphysics of the cloud layer* at different altitudes and locations, by direct sampling.
7) *Solar wind-atmosphere interaction processes and resulting escape* as a function of solar activity.
8) *In situ* determination of the *surface heat flow* of different landforms and structure-elements.
9) The *electromagnetic activity* monitoring and mapping of the planet.

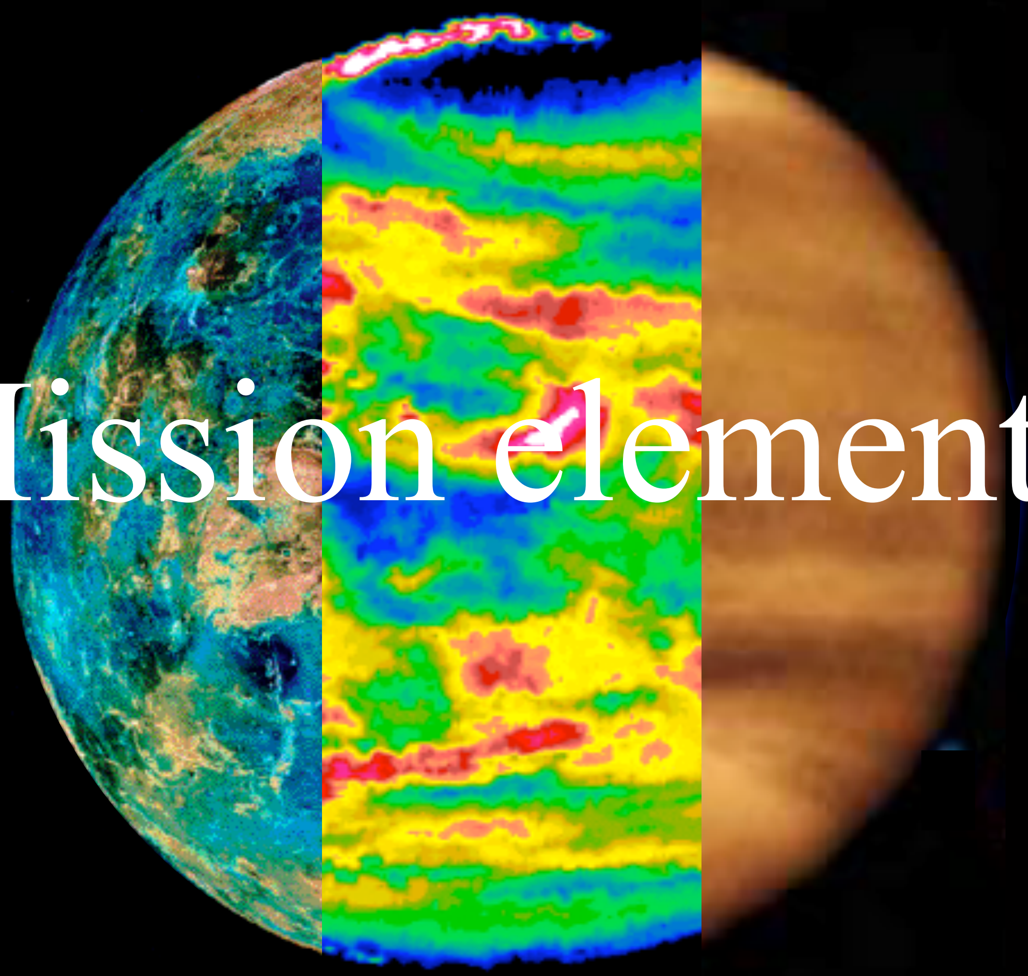
Main science goals (1)

- Investigation of the molecular composition of the lower atmosphere at various locations
- Study of the surface-atmosphere interactions
- Measurements of isotope abundance of heavy noble gases
- Systematic analysis of the surface both on the plains and tesserae
- Study of sub-surface by means of penetrating radar

Main science goals (2)

- In situ determination of the surface heat flow
- In situ accurate measurements of the temperature profiles below the clouds in order to quantify atmospheric stability, characterization of local turbulence, and wind measurements
- Direct wind measurements in the upper mesosphere
- Accurate measurements of radiative fluxes inside the atmosphere
- Determination of interior structure

Mission elements



Planetary orbiter

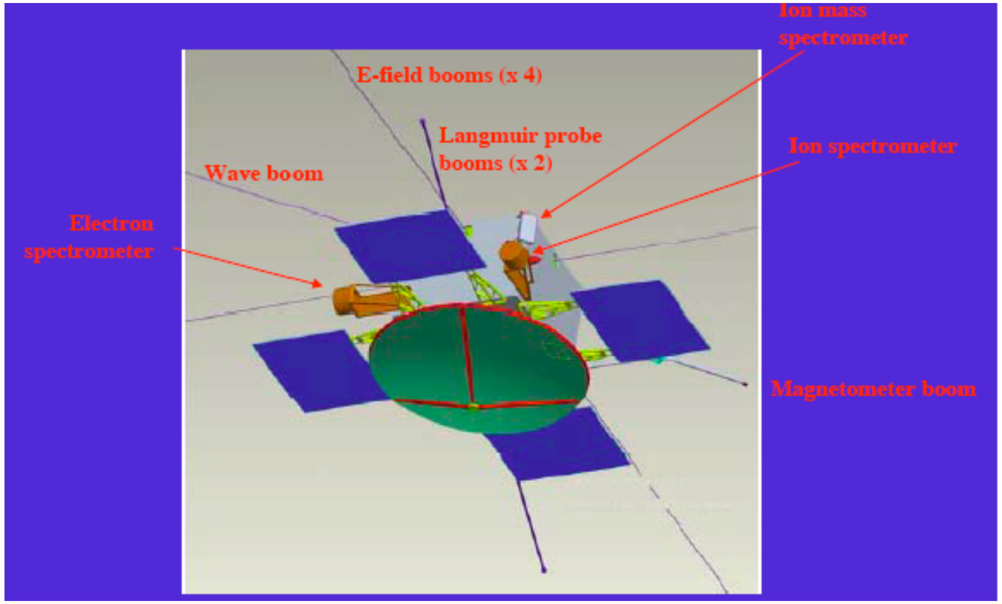
- Cf TRS VEP study of ESA's SCI-A.
- Possible use of aerobraking to save mass and optimize orbit :

> - Obtain a polar circular orbit with minimum propulsion resources, of particular importance for remote sensing of the atmosphere;
>
> - Place the satellite on an orbit with a low periapsis altitude (typically 150 km) for *in situ* measurements of the thermosphere, exosphere and ionosphere (in particular for characterising atmospheric escape), for highly spatially resolved gravity and/or magnetic field mapping, and mapping of the electromagnetic environment (in ULF-VLF to RF bands).

➔Should be studied by ESA!

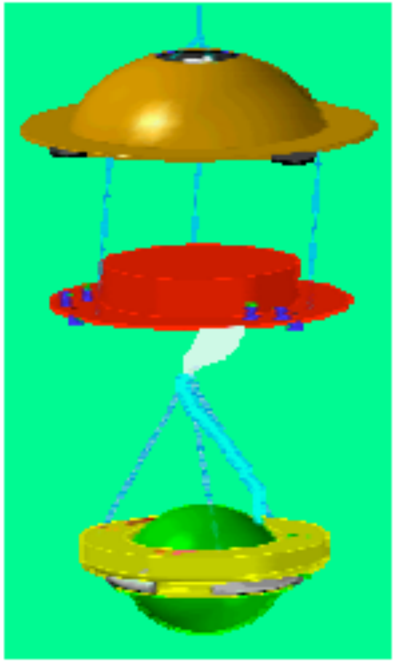
Plasma orbiter

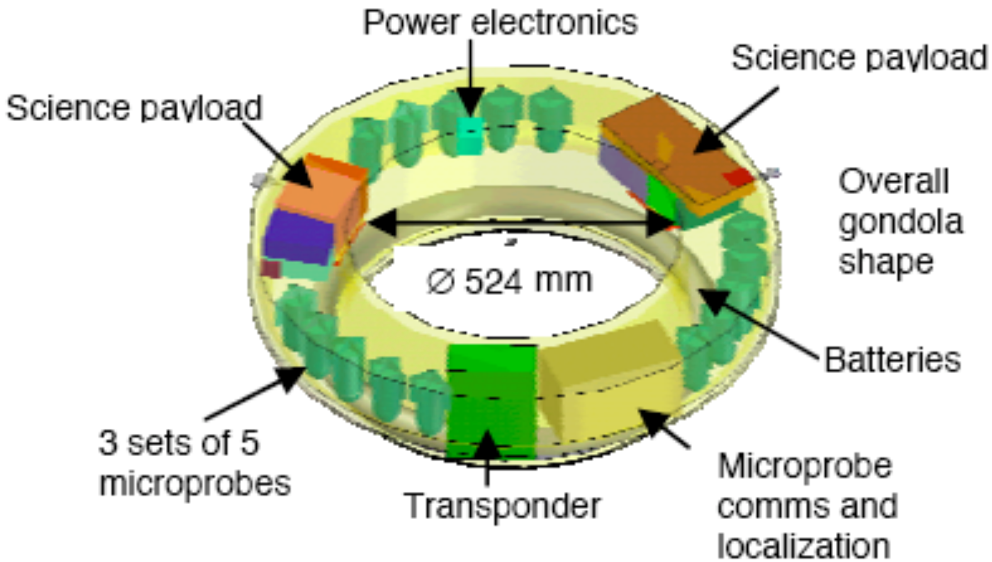
- Venus Ionospheric Science Probe (VISP)
- Royal Institute of Technology (Stockholm, Sweden)
- Sub-satellite (spinning platform)
- Low periapsis, high apoapsis
- Science payload ≈ 9 kg : DC **E**, **B**, waves, thermal plasma, electron spectrometer, ion spectrometer, ENA spectrometer.
- Total mass : 50-60 kg.



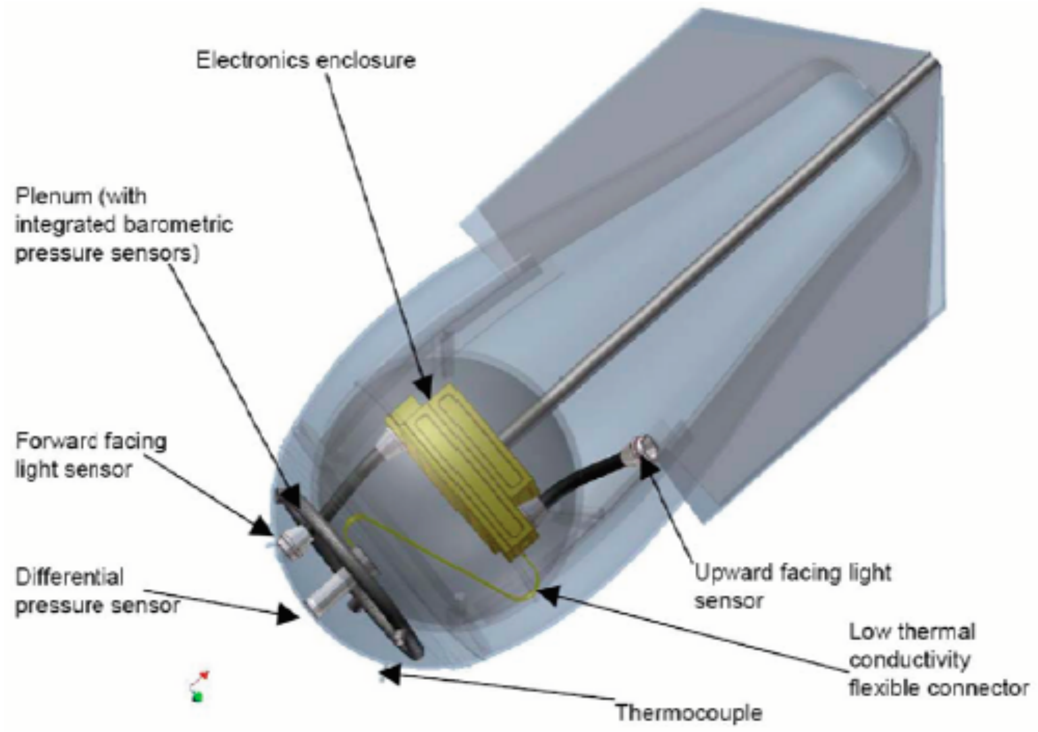
Cloud-altitude balloon

- Cf TRS VEP study of ESA's SCI-A.
- Super-pressurized balloon 3.6 m diameter
- Deployed at 55-65 km.
- 5 kg instruments + 3 kg microprobes (15 microprobes for dynamics monitoring)





Microprobes for cloud-altitude balloons



- Studied par Oxford University (United Kingdom).
- 100 g each.
- Radio-link with balloon for Doppler winds.
- Measurements, p, T, v, Vis, IR down to ≈10 km altitude.

Low-altitude balloon

- Preliminary design of a 10 km altitude balloon for the Lavoisier project (Chassefière et al, 2000).
- Ongoing R & D study for a 35-km altitude balloon at ISAS/ JAXA :
  - Water vapor pressurized balloon deployed at 35 km altitude (auto-inflation in the 45-35 km altitude range).
  - Solar cells, power ≈ a few watts, has a lifetime of 2 weeks.
  - Scientific payload of 1 kg (pressure, temperature, other sensors TBD : radiative flux, …), and an emitter allowing Doppler tracking by VLBI from Earth (wind).
  - Entry vehicle sized on the basis of the Hayabusa re-entry capsule.
  - Total mass of the entry vehicle : 35 kg.

Descent probes

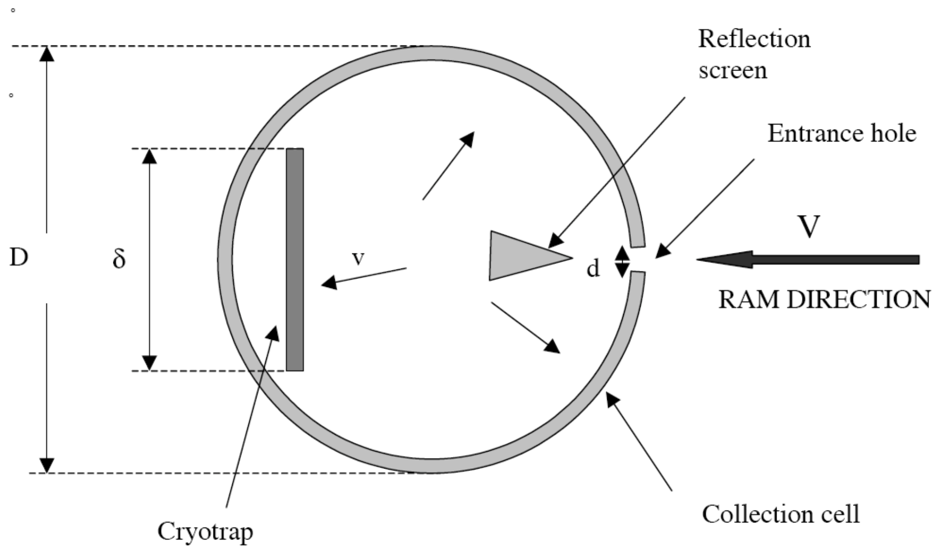
- Recent study by M. Van den Berg (SCI-A/2006/200/VEP/MvdB).
- Heritage of the Huygens probe is limited (different entry and environmental conditions).
- No operational lifetime assumed after landing.
- Scaling on Vega, PV, Jupiter Entry Probe study (NASA).

Assuming that the mass of the descent module equals 61% of the entry probe mass, and taking the JEP as the reference for the descent module design (communications to flyby), a rough indication for a Venus descent probe with payload masses from 5 to 30 kg can be derived:

Table 2: Top level estimate of a Venus Descent Probe

Payload mass (kg)	5	10	20	30
Descent module (kg)	~70	~90	~110	~130[3]
Entry probe (kg)	~115	~150	~180	~210

Atmosphere sample return system



- Several existing concepts : direct sampling through a pipe (CNES), use of aerogel (SCIM project), both during a very low altitude pass (≈50 km on Mars).
- Alternative concept proposed in answer to the Call for Ideas for the Re-use of the Mars Express Platform (2001).
  - Gas collected by cryotrapping during a flyby at ≈130 km altitude
  - Doesn't require fly-by at low altitude, in extreme thermal conditions.
- Total mass (cryocooler+collector+return capsule) < 50 kg.
- Possibility to use the return capsule developed for Hayabusa (ISAS/ JAXA)

Launcher

- Future low cost M5 launcher (Japan) : 150 kg in Venus transfer orbit.
- Soyuz-Fregat (SF-21b from Kourou) : 1450 kg in VTO.
- HIIA (Japan) : 1500-2000 kg in VTO.
- Ariane V : ≈3000 kg in VTO.
- Other (small) launchers (Russia) : TBD

Mission scenario

The step-by-step approach

- Step 1 (2005-2015) : European Venus-Express mission and Japanese Venus Climate mission Orbiter
  - Atmospheric and cloud dynamics
  - (Incomplete) global scale chemistry of the low atmosphere
- Step 2 (2015-2025) : in-situ mission, with the use of atmospheric probes (balloons, descent probes) and atmosphere sample return (in option)
  - Venus climate evolution
  - New data relative to atmospheric isotopic ratios, chemistry of the coupled surface/ atmosphere system, dynamics of the whole atmospheric system.
- Step 3 (2025-2035) : Long-lived landers for the characterisation of the interior structure and dynamics of Venus

Elemental scenarios (1)

Scenario A (Class M -?-) : one medium-size descent probe (Huygens-type) with no orbiter

Science focus: noble gases/stable isotopes, single place cloud/ atmospheric structure, surface mineralogy/ chemistry.

Core scenario A0

A descent probe of the Huygens type (40 kg payload) is deployed in direct insertion from a fly-by platform, which is used as a relay for data (in a way similar to the Cassini orbiter). This scenario is compatible with a launch by a Soyuz-Fregat. Objective 1 (noble gases, isotopes) may be reached, and partially objectives 2, 3 and 6 (atmospheric/ cloud chemistry, surface mineralogy and morphology at a single site).

Elemental scenarios (2)

Scenario B (Class M -?-) : one cloud altitude balloon with microprobes (cf VEP TRP study of ESA) with relay/science orbiter(s)

Science focus: noble gas/ stable isotopes, cloud particle composition and sizes, gas chemical composition at cloud level, wind, meteorological parameters and electromagnetic activity below the clouds down to the near-surface atmosphere.

Core scenario B0

A balloon probe is deployed at main cloud deck altitude (≈55 km), with a nominal mission duration of 15 days. Thanks to super-rotation, this balloon makes several turns around the planet. It is equipped with a few science instruments (radiation, chemistry, physics) and a set of 15 microprobes equipped with meteorological and radiation sensors. These microprobes, radio-linked to the aerobot, are released at different times and longitudes, and provide wind, density, temperature and radiation vertical profiles down to ≈10 km altitude. Gaseous and particle samples are analyzed in-situ by close remote sensing and chemical sensors. A relay orbiter is necessary due to the long duration of the mission (2 weeks). In the case of direct transmission to Earth, the data rate is only a few 10 bits per second (unacceptably low). A Soyuz launcher is used, and a small science orbiter (payload : 25 kg) can also be deployed. This orbiter is put on its final orbit by propulsive means.

Elemental scenarios (3)

Scenario C (Class M -?-) : Swarm of medium-size or small-size descent probes with no orbiter.

Science focus: multi-point vertical profiles of chemical composition and dynamics, multi-site surface mineralogy and morphology, surface/ atmosphere interactions

<u>Core scenario C0</u>

A number of small probes, similarly equipped with a science payload of 10-15 kg, are deployed in direct entry from a fly-by platform, which is used as a data relay. This scenario resembles scenario A but, instead of having one single medium-size probe, *n* small probes, with more focused science payload, are deployed above different sites, sampling latitudes, various landforms and elevations. *n* may be in the range from 3 to 5 (possibly 10). Each probe is equipped with physical, chemical and radiative sensors, providing vertical profiles of chemical composition and meteorological parameters, and investigating the mineralogy and morphology of landing sites, with the possibility to measure the thermal flux at different locations.

Preferred scenario (preliminary)

A combination of A and B, with one descent probe, and one balloon probe, is a Class-L mission. It doesn't allow multi-site exploration of surface, and a combination of B and C must be preferred, with optionally a Venus atmosphere sample return. A BC Class-L mission (swarm of descent probes and one balloon) is scientifically excellent, and favoured by the team.

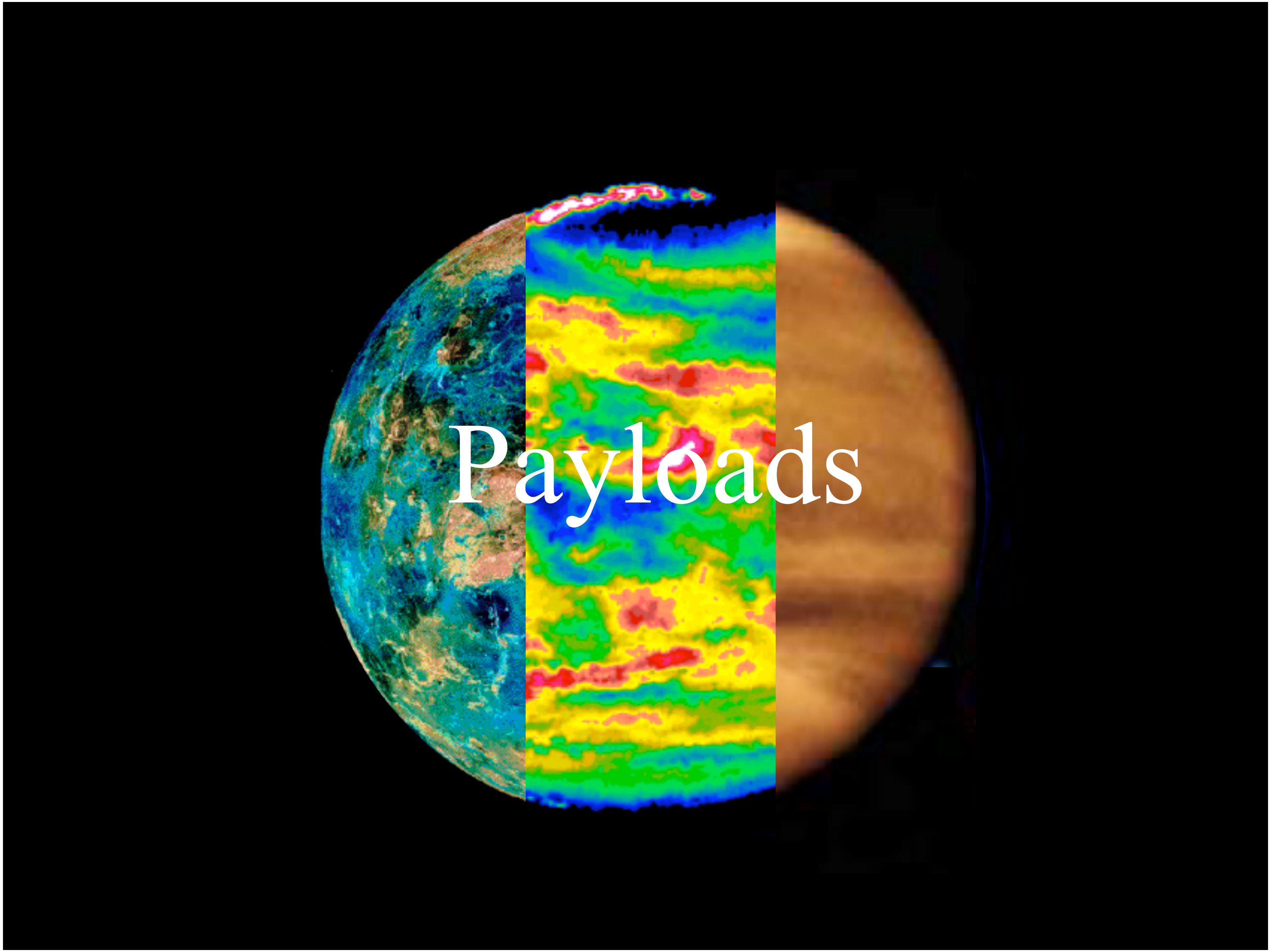
Scenario (class)/ Science objective	1	2	3	4	5	6	7	8	9	Scientific value
A (Class-M)	X	x	x			x		x		Moderate
B (Class-M)	X			x(orb.)	X	X	X		X	Moderate/large
C (Class-M or Class-L?)	X	X	X		x	X		X	x	Large
AB (Class-L)	X	x	x	x(orb.)	X	X	X	x	X	Large/Very large
BC (Class-L)	X	X	X	x(orb.)	X	X	X	X	X	Very large

The scenario BC (one orbiter, one balloon, a swarm of descent probes) is therefore ranked 1, but scenarios AB and C are also of great scientific value. Scenarios A and B are not favoured for a Venus-dedicated mission.

Note that scenario A and C, with no orbiter, could be scientifically reinforced if the fly-by platform is used to return a sample atmosphere.

International cooperation

- Scientific instruments (and sub-system) proposed by US, Japan, Russia, and Europe.
- Cooperation with Japan at mission element level under study (low-altitude balloon, thermal shield for descent probes, atmosphere return capsule, launcher…).
- Possible cooperation with Russia at mission element level to be studied (coordination with Venera D, launcher…).
- Possible cooperation with US at mission element level to be studied.
- Support by CNES for preparing the proposal (space mechanics, mission analysis…).


Payloads

Descent probes (1)

Acronym	Principle	Parameters	Mass	Power	TRL
		Atmosphere/ clouds			
VASI ACC	Atmospheric Structure Instrument Accelerometer	Density vertical profile (high atmosphere)	0.3 kg	1.7 W	9
Baro-HumiCap and/or	Pressure- and Humidity Sensor	p, H_2O			8-9
VIWS (USA)	High Temperature sensors and electronics	p, v , T CO, SO_2, O_2, NO_x, CH_4	Few grams	Few 10 mW	2-6
- Oxygen Fugacity Probe -- V-FOX (USA)	Electrochemical sensor	O_2	Few 0.1 kg, 0.4 kg	0.2 W, 0.4 W	5-6, 4-5
- ARD - CENTAUR	Natural radioactivity	Radon and daughter (Po, Bi, Pb)	0.3 kg?	A few W?	4, 2
- ATACAN - ITMS	Gas Chromatograph Mass Spectrometer (ToF or Ion Trap)	Chemical composition of cloud particles and atmospheric gas	3.1 kg, 1.2 kg	Peak : 50 W	4-8
VISS (proposed for Lavoisier) : 2 channels : VIS-NIR and IR.	*Imaging Visible/NIR/IR Spectrometer*	*Atmospheric composition : H_2O, CO etc…, surface mineralogy*	*2.1 kg*	*8,5 W*	
ISAV (boarded on Vega probes)	*Active UV absorption spectroscopy*	*SO_2 profiles*	*TBD*	*TBD*	*8*
Micro-lidar	*Active laser sounding (looking upward)*	*Highly-resolved vertical profiles of density and particles*	*TBD*	*TBD*	*1*

Descent probes (2)

Clouds (in addition to GCMS)					
MATROS-VEP	Attenuated Total Reflection Infrared Spectroscopy	Aerosol molecular composition	2 kg	10 W	4-9
XRS	X-Ray Spectrometer	Aerosol chemical composition (Z=11 to 41)	0.2 kg	3 W	
LMS	Laser Mass Spectrometer	Aerosol chemical composition	0.5 kg	5 W	4
VPN	Venus Polarization Nephelometer	Size/ info on composition	0.6 kg	2 W	3
Electricity/ Electromagnetic activity					
SAS2-VNS	Electromagnetic wave analyzer	Electric, magnetic signals	0.7 kg	<4 W	6-4
V-PWA	Permittivity Wave Analyser for Venus	Conductivity, electric field, acoustic waves, lightnings	0.5 kg	0.1 W	3-5

Surface					
SurVenTIS	Surface of Venus Thermal Imaging System (from descent probe, during descent)	Surface composition, oxidation state, thermal anomalies (large/ medium scales)	1 kg	5 W	4 (?)
GRS	Gamma-ray spectrometer	U, K, Th	0.2 kg	3 W	
VHS	Surface Heat Flow Sensor	Heat flux	TBD	TBD	1
Accelerometers (i.e. ACC-E, ACC-I of SSP/Huygens)	*Accelerometer*	*Mechanical properties of the surface*			*8*
Panoramic VIS/NIR camera system (may be an additional capability of SurVenTIS)	*Vis/NIR multiband imager (cf Serventis) (after landing)*	*Surface composition, oxidation state, thermal anomalies (small scale)*			
Total			≈15-20 kg (TBD)		

Payload mass : 15-20 kg

Consumption : ≈ 100 W

To be refined and optimized!

Cloud-altitude balloon

Name/ Acronym	Principle	Parameters	Mass	Power	TRL
Atmospheric dynamics					
Microprobes (10-20)	Noble gas spectrometer (static MS + separation line), long integration time	Noble gases, isotopes, stable isotopes, gas chemical composition	0.1 kg each, Balloon system : 1.5 kg	Balloon : <75 W	4-5
Meteo package (Baro-HumiCap + temperature)	Pressure, Humidity, Temperature Sensor	p, H_2O, T			9 (p), 8 (H_2O)
VERBE (proposed for Lavoisier)	*Radiometer at 3 wavelengths (1.7, 2.4, 3.7 µm) + wide band*	*Radiative budget at cloud level*	*0.5 kg*	*1.2 W*	
Accelerometer (i.e. ACC-I of SSP/Huygens)	*Accelerometer*	*Turbulence*	*0.1 kg*		*8*
Climate, chemistry and clouds					
- NGS - LMS - ITMS	Noble gas spectrometer (static MS + separation line), long integration time	Noble gases, isotopes, stable isotopes, gas chemical composition	4 kg	15 W	3-6
ACOA + pyrolysis device	PyrGC (PyrGCMS if coupled to the MS of NGS)	N_2, O_2, carbon species, sulfur species, noble gases, cloud	1.7 kg	30 W	8 (3 for optional Ionisation detector)

		particle composition			
VPN (USA)	Venus Polarization Nephelometer	Size distribution/ information on composition	0.6 kg	2 W	3
Electricity/ Magnetism/ Electromagnetic-acoustic activity					
SAS2-VNS	Electromagnetic wave analyzer	Electric, magnetic signals	0.7 kg	4 W	6-4
V-PWA	Permittivity Wave Analyser for Venus	Conductivity, electric field, acoustic waves, lightnings	0.5 kg	0.1 W	3-5
VBM (USA)	Magnetic field measurement	Continuous B component (global, crustal)	1.15 kg	0,5 W	9
LOD	*Lightning Optical Detector (proposed for Lavoisier)*	*Lightning at optical wavelength (778 nm)*	*0.1 kg*	*2 W*	
Total			12.3 kg		

Payload mass : ≈12 kg

Consumption : ≈ 100 W

To be refined and optimized!

Planetary orbiter

Payload mass : ≈45 kg

Consumption : ≈ 150 W

To be refined and optimized!

Name/Acronym	Principle	Parameters	Mass	Power	TRL
Meteors					
SPOSH	Panoramic camera	Meteors and lightnings	2.5 kg	10 W	
Atmospheric escape/ionosphere					
Venus EUV-FUV airglow spectrometer	UV spectroscopy in the 50-400 nm range	Atoms, ions, molecules in the thermosphere, ionosphere, and exosphere	4.5 kg	3 W average	3-4
TPIV	Thermal plasma investigation at Venus	Plasma density, temperature, drift velocity	0.9 kg	1.8 W	9
VIPI (Japan)	Venus ionospheric plasma imager	Mapping of Ultraviolet emissions of O and He	2.3 kg	5 W	6
SAS2-VNS	Electromagnetic wave analyzer	Electric, magnetic signals	0.7 kg	<4 W	6-4
Neutral and ion mass spectrometer	*Mass spectrometry*	*Neutral/ion thermal/suprathermal populations*	*4.6 kg*	*6 W*	
Middle atmosphere					
SWI	Submillimeter wave instrument	Doppler winds, temperature, H_2O etc… (60-140 km).	9.2 kg	49.5 W	
Accelerometer (aerobraking phase)	Measurement of deceleration near periaspis	Atmospheric density	1 kg	1 W	
Subsurface and interior					
VRS (USA)	Venus Radar Sounder	Layering of 1-3 km of Venus crust	17 kg	64.5 W	9
VISIS	Doppler sounding of ionosphere	Ionospheric fluctuations created by quakes and volcanic events	- Emitter : cf VRS - Receivers : 2 add. satellites		
X-band transponder + USO	*Doppler tracking*	*Gravity field anomalies*	*2 kg*	*2 W average*	
Total			44.3 kg	146.8 W	

Plasma orbiter (VIPS/ Sweden)

Sensor	Configuration	Mass, kg	Comments
DC electric field	4 wire booms, 10 m each	3.0	BC design
Magnetic field	Flux gate on one still 1 m radial boom	1.0	
Waves	One wire boom	0.5	
Thermal plasma	2 Lagmuir probes on 50 cm booms on solar panels	0.2	
Electron spectrometer	Top-Hat ESA	0.5	MEX 0.3 kg
Ion spectrometer	Same as electron spectrometer	0.5	
Ion mass spectrometer	2 identical sensors, 0.5 kg each	1.0	BC design
Central DPU		1.0	
ENA imager	2 identical sensors	2.0	Optional
Total		9.7	